INTEGRATION AND OPTIMIZATION OF PROJECTILE DESIGN MODELS

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ABSTRACT

This paper presents an approach towards the development of an integrated design environment with design optitimization capabilities wherein the projectile design, geometry, or changes to those of an existing projectile, will be optimized with respect to performance requirement(s). Additionally, the design process will be simplified by the integration between predictive codes in this environment. This environment will include a procedure for making first cut or rough estimates in the initial stages of design so that lengthy and expensive design code runs can be reserved for promising design configurations.

1. INTRODUCTION

Projectile design is a process that entails many complicated procedures which involve many aspects of knowledge, experience and interrelationships between disciplines. In the past, these decisions were typically made sequentially by individuals or teams with expertise in various areas of the design process.

Traditionally, the design process utilizes a combination of hand estimations, predictions from software codes, and physical testing at each phase of the design process, iteratively, in order to arrive at an optimum configuration. Each discipline involved in the design process has over-time developed its own set of automated tools. There have been some efforts made to integrate the various areas of projectile design; the software code PRODAS comes closet to achieving this. However, there have not been any known attempts at creating an overarching design environment where optimization of the projectile's design is driven by changes in the target set. In the present environment of budget pressure, changing technology, and rapidly evolving threats, the requirements for increased performance and decreased design cycle times for cannon-fired projectiles have given rise to a strong need for an integrated and optimized design system. This need is common to small, medium and large caliber projectiles.

2. AIM AND OBJECTIVES

In recent years, many advances have been made in projectile design and performance prediction codes. These programs cover the areas of projectile mechanical design and manufacture, interior ballistics, exterior ballistics, and terminal ballistics. There have been attempts at automating the performance predictions of projectiles given a certain design or geometry . However, such analyses have not addressed optimization with regard to system level requirements (e.g. target sets or platform changes), nor do they provide for first cut or rough estimates of candidate designs.

Additionally, many of the codes used are considered specialty software, and need to be run by technical experts in their areas. They are not user friendly, especially in regard to their input interfaces. The available codes also do not interact (or talk) with one another, or do so in a very limited manner.

This system will address these important issues, and is expected to be a significant step forward in providing a state of the art, integrated design environment with design optimization capabilities that will speed the development of high performance projectiles of all sizes, and optimize their performance against present and future threats.

This effort involves development of a detailed architecture for integrating tools used at all stages of the

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
01 NOV 2006	**N/A**	**-**

4. TITLE AND SUBTITLE
Integration And Optimization Of Projectile Design Models

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Armament Research, Development and Engineering Center Picatinny Arsenal, NJ 07806

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002075.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

projectile design process, and provides a method for "feeding" results between models in order to more efficiently proceed through the design process. This will include requirements matching tools, physical configuration design tools (including interior ballistic, aerodynamic and structural models), flight prediction models (including guidance models for smart projectiles) and terminal effects predictors. Additionally, logic will be incorporated that will determine if prospective designs will have a high chance of meeting the new or revised performance requirements, and if not, recommended a path to achieve them.

3. APPROACH

Different approaches for projectile design were studied and compared and the most pertinent techniques were considered for the development of the methodology of this system. Based on this work, an integrated approach, with optimization, and a graphical user-friendly interface is being developed.

This system architecture will be useful for optimizing the design and performance of all calibers (sizes) and types of gun fired projectiles. This will include projectiles that are fin stabilized (statically stable) and spin stabilized (gyroscopically stable), those that defeat their targets due to kinetic energy and those that use various warhead devices to defeat their targets.

The demonstration system, while maintaining its generic nature so that it can be utilized across all calibers, stability types and warhead types, will initially be functional for optimizing the design and performance of a 120mm, statically stable, kinetic energy type projectile. This projectile type is of prime importance to the US Army for the defeat of armored targets. The extensive performance data available makes it an ideal test case for verification of this design tool concept.

While the system architecture is sufficiently broad to allow for detailed modeling of all aspects of projectile design and performance, this system will first concentrate on optimization of ballistics and the defeat of given target sets. The full integration of all phases in the refined analysis (such as advanced vulnerability codes that need special access to run on supercomputers) will be left for a future improvement effort. Some work in this area has been accomplished, however, at this time it is not mature enough for inclusion. Another challenge is that incorporating these refined codes into this system will need to be accomplished with an Internet-based interface.

Requirements management software is reaching a level where it may be possible, in the future, to have weighted performance requirements pass automatically to the design engineer's software suite. A survey of typical requirements management software is presented in Table 1. At this stage in the development of our system, the user will be manually selecting (via the GUI) one performance requirement to be met (e.g. target thickness).

A concurrent goal of this system is to reduce projectile design cycle time and increase the efficiency of the design process. Typically, to run the full suite of codes required to obtain a design that will meet a new or changed set of performance requirements, a designer, or more likely a team of designers each with specialty knowledge in the pertinent areas, would take months to run a similar level design and optimization study. Additionally, the design team may not realize until they are fairly deep into the design process and after significant time has passed that their approach may yield a design that will not meet the performance requirement. The proposed system will have the capability to determine if the changes being considered will enable the requirements to be met and if not, how far from being met the proposed design is. The system will also recommend a path to follow should the proposed design changes be far from meeting the performance requirements. This will occur first in the early stage, and again at the end of the design refinement stage, thereby increasing the efficiency of the design optimization process.

It is hoped that the proposed system of integration and optimization of projectile design models will reduce the time required to modify a projectile design to meet new requirements from months to weeks. While a wise designer will still solicit the advice and assistance of subject matter experts, the system should allow a significant reduction in the man hours needed to identify design improvements. As previous studies have indicated, up to a 50% reduction in man hour costs during the design phase could be realized.

4. BRIEF REVIEW OF DESIGN METHODOLOGIES

There have been many changes in the way that end-to-end projectile design is accomplished. Presented here is an overview of the various techniques used.

4.1 Traditional Methods

Traditionally, projectile designers used a combination of formulas, charts, and rules of thumb and verified their predictions with experiments. These experiments included mechanical testing, wind tunnel testing, flight testing, and target effects testing. Out of many years of such experimentation, useful references evolved, such as the Army Design Handbook and Pamphlet series, specialized notes, and textbooks. These are not completely ignored in contemporary procedures and codes and will be included in this environment. These basic methods and models will be part of the initial loop (or rough cut) phase estimates in this system.

4.2 Computational methods

There are many software packages available to assist in the mechanical, aerodynamic and lethality design of a projectile. Table 2 shows a listing of computational design and performance analysis tools currently available to the projectile designer. While not completely exhaustive, this list comprises the most important tools in each area of projectile design.

4.3 Current Methods

Present day designers use a combination of these tools, and in most cases, work as an integrated product team that is comprised of subject matter experts. These teams typically include one or more members from each discipline that is required in the design and fielding process. This includes mechanical design, heat transfer, interior ballistics, exterior ballistics, terminal ballistics, manufacturability, safety, and logistics. Each team also has a project manager that would be responsible for cost, schedule and requirements flow down. Each subject matter expert member of these teams typically will use traditional methods as first cut approximations, followed by the use of software models (table 2), and compare the outputs of those models with expected outcomes and performance requirements. These experts must also interface with each other, and must ensure that their solutions reside in the design space of the complete system.

5. PROPOSED INTEGRATION AND OPTIMIZATION SCHEME

This system will incorporate an overarching scheme that will seamlessly link all of the phases of the design process, with data passed between blocks and individual models with little or no user intervention, except at certain key decision points. For the demonstration system, the user requirements will be manually entered.

5.1 Constraints of demonstration system

As discussed under III. Approach, the prototype system will initially be functional for optimizing the design and performance of a 120mm, statically stable, kinetic energy type projectile, and will first concentrate on the optimization of ballistic properties and the defeat of given target sets. The architecture will be broad enough to allow additional capabilities to be added without modifications to the system structure.

5.2 Description of prototype system block diagram

A block diagram and flow chart of the complete system is shown in Fig. 1. The blocks are broken up according to major phases of the system, and are intended to indicate where system inputs, calculations and outputs occur. Each of the phase blocks is labeled as Figs. 2 through 7.

5.2.1 Feedback feature

Figure 1 shows, to the left and right of the block diagram, refinement connections. These are an important aspect of the system's architecture. The first is the refinement connection that links the area of focus block in Fig. 4 and the user review of performance block in Fig. 6, and is on the right side of the block diagram. This is used to check relatively quickly and at a high level if the existing design can meet the desired performance improvement within reasonable bounds of modification, or if a new design should be pursued. The other refinement connection, shown on the left side of the block diagram, connects model review block in Fig. 6 back up to the area of focus block in Fig. 4. This feedback connection checks to see if the design, after having passed through the high level models (Fig. 7, pink box), is anticipated to have the required performance and is ready for physical testing.

5.2.2 Projectile selection

The projectile type, and launch platform is selected by the user. Figure 2 shows a wide selection of direct and indirect fire platforms. These include handheld firearms, mortar weapons, artillery weapons and tank cannons. These will be able to be phased in as selectable options in the future; this demonstration project will concentrate on the Direct Fire, M256 120mm smooth bore cannon.

5.2.3 Ammunition type

After selection of the firing platform, the ammunition type to be optimized and target information is entered. In future versions, when full linkage to requirements software is incorporated, it is anticipated that this will occur automatically. In our prototype system the user selects the ammunition type and the target parameters. These actions are shown in the block diagram in Fig. 3, and the input screen for these parameters from the GUI is shown in Fig. 8.

5.2.4 Area of focus selection

The user makes a decision, based on the target set, which of three areas of focus to use as the start of the optimization process. The potential performance improvement areas are: accuracy, lethality and range. Each of these is shown in green boxes in Fig. 4. Within each of these modules, the pertinent calculations for that performance area will be performed. For example, if the target range has been increased, the range performance factor would be selected as the first area of consideration for performance improvement. If target hardness of defeat has risen, the lethality performance factor would be the first area considered, and if greater accuracy was needed to hit a new or smaller target, the accuracy performance factor would be the first area considered.

5.2.5 Desired performance improvement and use of parametric equations

At this stage, shown in Fig. 5, the user selects the amount of performance increase that will be deemed acceptable. At this point, tables of parametric equations are used to make first cut approximations to see if existing designs could be modified to meet the new performance requirements, in accordance with the area of focus selection from Fig. 4. The output of this stage is a model configuration that is built using current components from the existing design that have been altered (within the bounds of the performance factor) to achieve the desired level of performance. This information is then transferred to the PRODAS program (Fig. 6) for a first cut ballistic evaluation.

5.2.6 Applicable Features of PRODAS

The projectile design software package PRODAS will be used in the preliminary design check phase as shown in Fig. 6. It will also be used later in the final, refined analysis stage (Fig. 7). At the current stage, it will be used to check the proposed design for physical and aerodynamic feasibility. The output of this stage is subject to user review, and if not acceptable, the right side feedback loop is utilized to begin the analysis anew, either changing the requirement level, or the area of focus.

5.2.7 Detailed level configuration analysis

In this stage, the high level analysis models are run. These models are shown in the pink box in Fig. 7. These models will include manufacturing, interior ballistics, in-bore dynamics, structural, physical properties, exterior ballistics, and terminal ballistics analyses. These high level codes will be called as needed, and some that run on supercomputers may require web linkage for input and output data transfer, as well as permission from or coordination with their owners. The output of this block is then reviewed and checked against the performance requirements, and a recommendation is then made to either return to the area of focus for iteration or to proceed to physical testing with what should be an acceptable design.

5.2.8 Use of Python for information transfer between models

For this application, Python was chosen as the programming language because it is one of the easiest-to-learn and most powerful programming languages for integrating different, pre-existing software packages. More importantly, building GUIs (Graphical User Interfaces) in Python is facilitated due to its proclivity towards rapid development. Additionally, Python is an open-source project, which means it is distributed and can be developed under a special license that allows it to be used for free by anyone on many different platforms. For the short time it has been in existence, web-rings, forums, and many other support structures have already been developed and are widely used, and many references and programming aides are at our disposal.

5.2.9 Sample input screens and prototype system description

To date, we have developed the two front sections of the over-all program. Firstly, Fig. 8 shows the initial user interface. Here, the user will be able to choose the baseline model for their projectile development. Existing models can be chosen from the tree menu on the left. The right side of the window allows the user to choose the desired target qualities as well as the required hit probability. Finally, the user will select an area of focus, upon which the bulk of analysis occur through the development of the new design.

After the initial selections are made, the information will be transferred to the processing part of the program where changes can be made to the physical properties of the projectile. In order to facilitate information transfer with format discrepancies, graphical Python interfaces are also being developed for existing text-based programs that have been used historically in projectile design. One of the programs being given an improved interface is TRAJ, a FORTRAN six degree of freedom trajectory prediction program. The new interface is shown in Fig. 9. Form factors and aero coefficients will be taken as automatic or manual inputs and trajectories for the specified projectile will be calculated using the pre-proven, original kernel of the FORTRAN program. The results will then be formatted and transferred to the next stage of the program to compare the simulated performance with the desired design characteristics.

6. CONCLUSION

This system architecture will be useful for all calibers (sizes) and types of gun fired projectile design. This will include projectiles that are fin stabilized (statically stable) and spin stabilized (gyroscopically stable), those that defeat their targets due to kinetic energy and those that use various warhead devices to defeat their targets.

The demonstration system being developed, while generic in structure across all calibers, stability types and warhead types, will initially be functional for optimizing the design and performance of a 120mm, statically stable, kinetic energy type projectile. This particular projectile is of prime importance to the US Army for the defeat of armored targets; additionally, for our purposes it is ideal since it has extensive data available for verification of our design tool.

Additionally, while the system architecture will be sufficiently broad to allow for detailed modeling of all aspects of projectile design and performance, this demonstration will concentrate on optimization of ballistics and the defeat of given target sets. It will be recommended that the full integration of all phases in the refined analysis (such as advanced vulnerability codes that need special access to run on supercomputers) be included as future improvements.

It is anticipated that a prototype version of this system will be demonstrated in the near future.

The long term objective of this effort is to completely integrate and optimize the models used in the design and system engineering process of all types and sizes of gun fired projectiles.

ACKNOWLEDGMENTS

The authors wish to thank: Mr. William Indoe for his efforts on this project; Mr. Vincent Marchese, the Chief of the Aeroballistics Division at Picatinny Arsenal, for his unconditional support and encouragement; and the Enterprise Management Office of the US Army ARDEC for sponsoring this work under research account number 5-27215.

NOTE on GRAPHICS

All tables and figures are available at the Army Knowledge Online website by following the link: https://www.us.army.mil/suite/folder/476323

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